[redacted]

GPO PRICE $ ______

CFSTI PRICE(S) $ ______

Hard copy (HC) 2.00

Microfiche (MF) .50

ff 653 July 65

N65-34217	
(ACCESSION NUMBER)	(THRU)
30	1
(PAGES)	(CODE)
CR 64912	20
(NASA CR OR TMX OR AD NUMBER)	(CATEGORY)

FACILITY FORM 602

JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA

RE-ORDER NO.

SMYTH RESEARCH ASSOCIATES
3555 AERO COURT
SAN DIEGO, CALIFORNIA 92123

FINAL REPORT
RADIO METEOROLOGY AT JPL
GOLDSTONE PIONEER STATION
July 14, 1965

Prepared for

JET PROPULSION LABORATORY
P. O. NUMBER AB-327179

NAS 7-100

SRA-452

FINAL REPORT

RADIO METEOROLOGY AT
JPL GOLDSTONE PIONEER STATION
July 14, 1965
by
John B. Smyth
Leo B. Cashman

July 1965

ABSTRACT

34217

The purpose of this investigation was two fold: to determine the macroscopic refractive index structure of the tropospheric region through which the Marine-Mars signals were propagating and to evaluate the local microscopic refractive index variations which could cause significant phase variations of the received signal during the time of the measurements around 7:00 p.m., July 14, 1965. A study of meteorological data taken from radiosonde ascents above Yuma, San Diego, and Las Vegas together with surface observations at Goldstone yielded a value of 2.27 ± 0.03 meters for the radio depth of the troposphere.

If the air between two and five kilometers had been saturated, an additional 0.14 meters path length would have resulted. Cumulus cloud activity could cause changes of this magnitude. Fortunately, no such clouds were present along the transmission path. It is extremely unlikely that fluctuations as large as ± 0.02 meters took place over the Pioneer Station during the time interval 1900 - 2000 on July 14, 1965.

TABLE OF CONTENTS

I. SYNOPTIC WEATHER SITUATION OVER SOUTHERN CALIFORNIA

The summer season for Southern California lies within the belt of subtropical, anticyclones. With the absence of surface frontal activity, a stagnant circulation exists. Because of the persistence of high-level, anticyclonic circulation aloft, pronounced subsidence is maintained throughout this season. The air next to the ocean is cool because the water temperature is low. Water vapor is deposited in this cool stratum in juxtaposition with the ocean surface. By July this moist marine layer is fairly thin and usually its top is well below two kilometers. Above the marine stratum the air is characterized by very low humidity and very high temperature due to adiabatic heating during subsidence. Variation in height and magnitude of temperature inversion is the governing factor in daily weather phenomena along the California coast. The well-known Los Angeles smog is an example of the complete lack of vertical mixing. There exists a very close correlation between the height of the base of the inversion, the pressure at 10,000 feet, and the lapse rate of temperature between the 5,000 and 10,000 foot levels. With the intensification of the pressure field aloft, it has been found that the lapse rate of temperature approaches the dry adiabatic condition; and thus, under these conditions, indicates increased subsidence. Consequently, the depth of the marine layer is diminished by the lowering of the base of the inversion.

The period of July 13 and 14, 1965, was an exception to the usual summer weather over Southern California since considerable moist air was brought in aloft from the Gulf of Mexico. The weather of this situation, which was known as Sonora Weather, brings warmer temperatures and higher humidities to most areas of Southern California. Daytime heating over the mountains and deserts produces enough instability to cause cumulus and cumulo-nimbus clouds with many rain showers and thunder storms. Although cumulus clouds were generated by high ridges around the Goldstone location, the air above Goldstone Pioneer Station was relatively clear during the late afternoon and early evening of July 14, 1965. Scattered cirrus clouds were over the Goldstone location during the period between 1800 and 2000 on Wednesday afternoon, July 14.

Under normal conditions it would be expected that the radiosonde data from Point Arguello, Los Angeles, San Diego, Yuma, and Las Vegas would give an indication of the degree to which the air aloft has been mixed, and information on the stratification of the index of refraction over a wide region circumscribing the Goldstone location. (See figure 1.) However, the air trajectory during the period of July 14, 1965, indicates that Yuma, San Diego and Las Vegas are most representative for the Goldstone location.

II. TROPOSPHERIC REFRACTIVE INDEX

A. ERROR ANALYSIS

In atmospheric studies, the small deviation of the index of refraction from unity is studied by introducing the refractivity, N, defined as $N = (n-1)\ 10^6$, where n is the refractive index of the air.

The refractivity of the atmospheric gas is theoretically predicted by a functional relationship of the form

$$N = \frac{A}{T}\left(P + \frac{Be}{T} \right)$$

where P is the total pressure, T is the absolute temperature and e is water vapor pressure. The constants A and B have been determined empirically to be:

$$A = 77.6\ \frac{K^{o}}{mb}\ , \text{ and } B = 4.810\ K^{o}.$$

Thus, if meteorological parameters, P, T and e are measured for some time and place in the atmosphere, the refractivity can be calculated by the above formula. Refractivity values are tabulated in Appendix I for actual radiosonde weather data of Las Vegas, San Diego, and Yuma.

The effects of small errors or fluctuations in T, P and e are determined by the partial derivatives of N with respect to the appropriate independent variable. From the formula, it is seen that these partial derivatives are:

$$\frac{\partial N}{\partial P} = \frac{77.6}{T}\ ,$$

$$\frac{\partial N}{\partial e} = \frac{3.73\ 10^{5}}{T^{2}}\ ,$$

TABLE I

ERROR ANALYSIS

Approx. altitude above sea h (km)	Weather Conditions P (mb)	Temp. °K	Dew Pt. °C	e (mb)	$\frac{\partial N}{\partial P}$	Pressure error ΔP	Resulting error in N ΔN	$\frac{\partial N}{\partial e}$	Error in dew point ΔT	Equivalent error in vapor pressure Δe	Resulting error in N ΔN	$\frac{\partial N}{\partial T}$	Temp. error ΔT	Resulting error in N ΔN
1.0	900	304.5	9	13.7	.25	1 mb	.25	4.04	.5°C	.4 mb	1.61	1.05	.5°C	.503
1.5	850	290	9	13.7	.27	2 mb	.54	4.3	"	.2	.86	1.0	"	.5
3.2	700	286	0.0	6.1	.27	2 mb	.54	4.5	"	.15	.67	.86	"	.43
5.9	500	262	-6	3.6	.30	3 mb	.90	5.5	"	.020	.15	.60	"	.303
7.6	400	253	-28	.47	.31	3 mb	.91	5.9	"	.013	.077	.50	"	.25
9.6	300	237	-48	.05	.33	2 mb	.66	6.8	"	10^{-4}	6.8×10^{-4}	.42	"	.21
12.4	200	216			.36	1 mb	.36					.311	"	.15
16.6	100	210			.37	1 mb	.37					.176	"	.088

and

$$\frac{\partial N}{\partial T} = -\frac{77.6}{T^2}\left(P + \frac{9620\ e}{T}\right)$$

In order to determine the effect of probable errors in T, P and e, these partial derivatives may be evaluated at the approximate values of P, T, e for the atmosphere which is being studied. In Table I are tabulated atmospheric conditions typical of those found in July radiosonde weather data of Southern California, and which are similar to conditions at Goldstone Tracking Station on 14 July 1965. For the weather conditions found in each row, the partial derivatives are evaluated and then multiplied into corresponding estimated errors in P, e, or T, to give a resulting error in N, ΔN. At the lower altitudes such as around the 900 mb pressure level, errors in N are expected to be mostly due to errors in humidity. As has been pointed out elsewhere, changes in water vapor associated with the presence of clouds can have a marked effect on the refractivity, N.

At higher altitudes, above 6 km, the water vapor content dwindles, and above 8 km it becomes negligible. Consequently, at these higher altitudes, the only measurable changes in N are due to changes in temperature and pressure.

B. RADIOSONDE PROFILES

At elevations near the Earth's surface the water vapor content is the dominant variable. At higher elevations where the atmosphere consists of almost one hundred per cent dry constituents, the density variation with elevation controls the index of refraction variation. Above the 700 mb pressure level the refractivity decreases exponentially with elevation and remains quite stable regardless of weather conditions below. At these higher altitudes the atmospheric conditions above San Diego, Yuma, and Las Vegas were very similar to one another over the period of July 14 - 15. This is shown in figure 2 by the fact that the eight data points taken from the three different

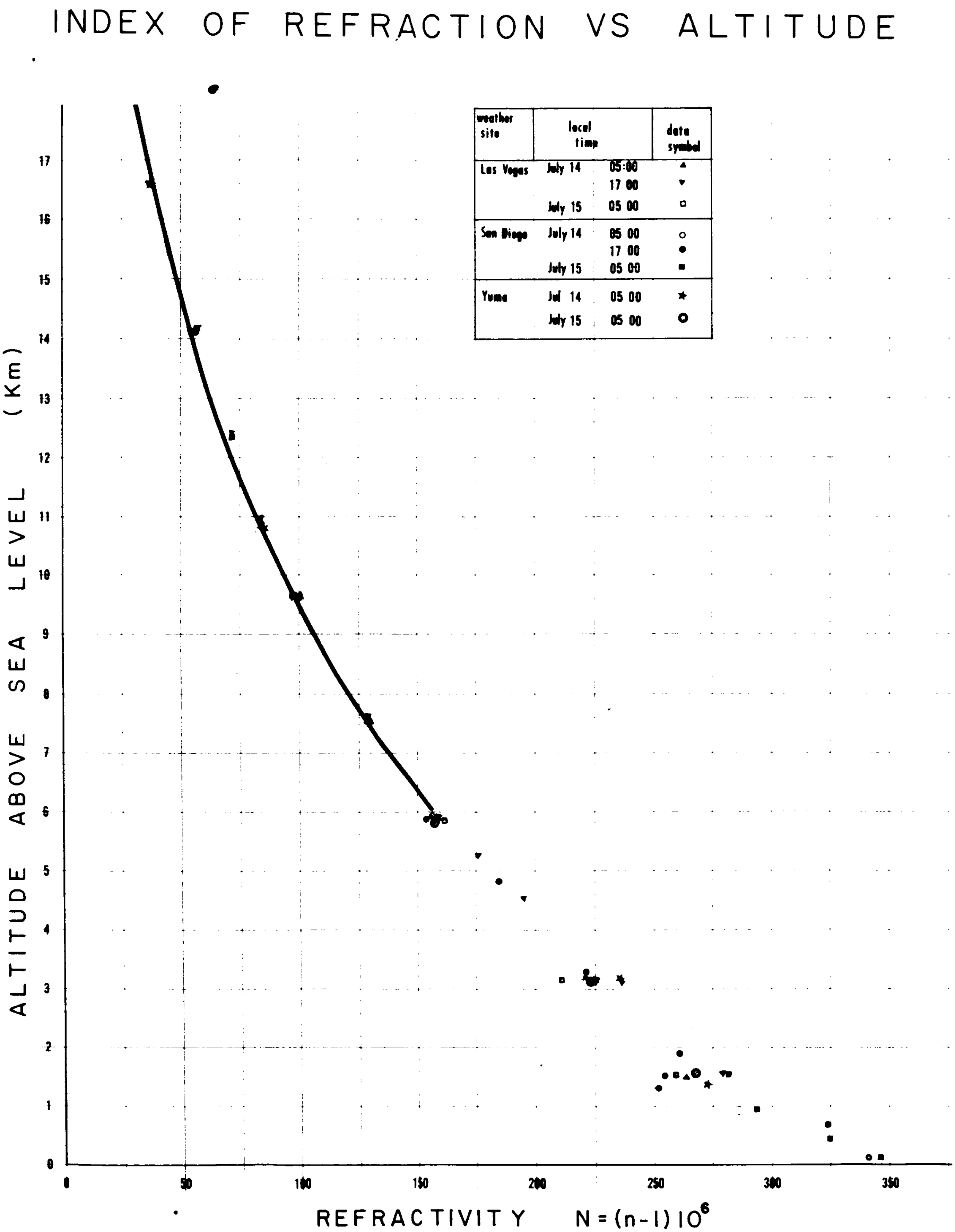

Figure 2. Index of refraction vs altitude

towns, all fall on practically the same spot, wherever data was recorded above 6 km. Above 6 km, the N profile for July 14 is very well represented by

$$N = 349 \ \exp. \left[-0.1326 \ h \right]$$

where h is in kilometers. This curve was selected as the best fit to the radiosonde profiles taken at Yuma, San Diego and Las Vegas. These data are shown in figure 2. The radiosonde data for these stations are tabulated in Appendix I. Between 2 km and 6 km the N profile is again always closely exponential in form, but in this interval, the exact positioning of the curve depends upon the meteorological conditions. Below 2 km the N profile may be extremely variable but is adequately represented by a number of linear segments. For the Goldstone location at the time of interest the data in the altitude interval from 1 to 6 km appear to be contained between the two following curves:

$$N = 316 \ \exp. \left[-0.1176 \ h \right],$$

$$N = 310.5 - 25.5 \ h.$$

C. INDEX OF REFRACTION FLUCTUATIONS

Measurements reported by Crain [1] indicate that the magnitude of refractive index change over spatial distances less than 100 feet are very small at elevations above 1,000 feet. The major refractive index changes were found to be associated with fluctuations in air moisture. Flying at 1,000 feet along the Atlantic coast line changes in N up to 15 units were observed over distances of the order of 300 to 500 feet (rms values 3 N units). The associated temperature changes were only one to two tenths of a degree centigrade. Bussey [2] finds that scale sizes of 5 meters have changes less than 0.1 N at all times. For sizes 100 to 500 meters the average ΔN is 1.5, for 1,000 to 6,000 meters the change in ΔN is 4.5.

Refractive index changes of 10 to 25 N units has been observed at the boundary of cumulus clouds. The convective activity associated with the latent heat of condensation carries water vapor from levels as low as 5,000 ft. to elevations in excess of 25,000 ft. The falling ice and water particles evaporate and supply water vapor which increases the index of refraction within the cloud. Fortunately, all cumulus cloud activity was well off the propagation path between the Pioneer Station and the Mars spacecraft during the time 1800 to 2000 on 14 July 1965.

The diurnal variation of the temperature at the Earth's surface creates a temperature inversion which progresses up in elevation during the morning hours until finally the normal daytime lapse rate of temperature is established. This temperature inversion creates a stratified region in which atmospheric waves can exist. A theoretical consideration indicates that atmospheric wave motion can occur at any surface in the atmosphere where there is a rapid change in wind velocity with height and a stable stratification of temperature. Such conditions are best fulfilled at temperature inversions. The wind shift supplies the energy that sets up the wave motion. Gravity acts as a stabilizing or restoring force. The waves may be stable or unstable depending upon their wave length, which in turn depends on the density, the wind speed difference on the two sides of the temperature inversion and on the actual lapse rates of the temperature in the two regions below and above the inversion.

For given values of density, wind velocity differences and temperature lapse rates, there is a critical wave length below which wave motion is unstable. The smaller the temperature inversion, the longer the wave length that will become unstable. However, all wave lengths above this critical value will remain stable because of the gravitational effect. A determination of the critical wave lengths involves solutions of the equation of the motion and equation of continuity under the specified conditions of temperature lapse rates and density variation. For the case of ordinary adiabatic lapse rate, waves of unlimited wave length would be unstable since there would be no restoring force on a parcel of air that is either displaced upward or downward. There is no restoring force, just viscous type forces. This is the region where turbulent air blobs are developed because of the shearing effect. In addition, there are leeways set up by the air flowing over mountain ridges. This might be a source of turbulent blobs in the air above the Goldstone site. An investigation of these two aspects of the problem is beyond the scope of the current investigation and will not be discussed further here.

III. METEOROLOGY AT GOLDSTONE

A. TEMPERATURE

Wet bulb and dry bulb temperature measurements were made at a point approximately six feet above the surface of the earth at three separate locations. Location A was at 1,000 feet east of the Pioneer Antenna Site; Location B was

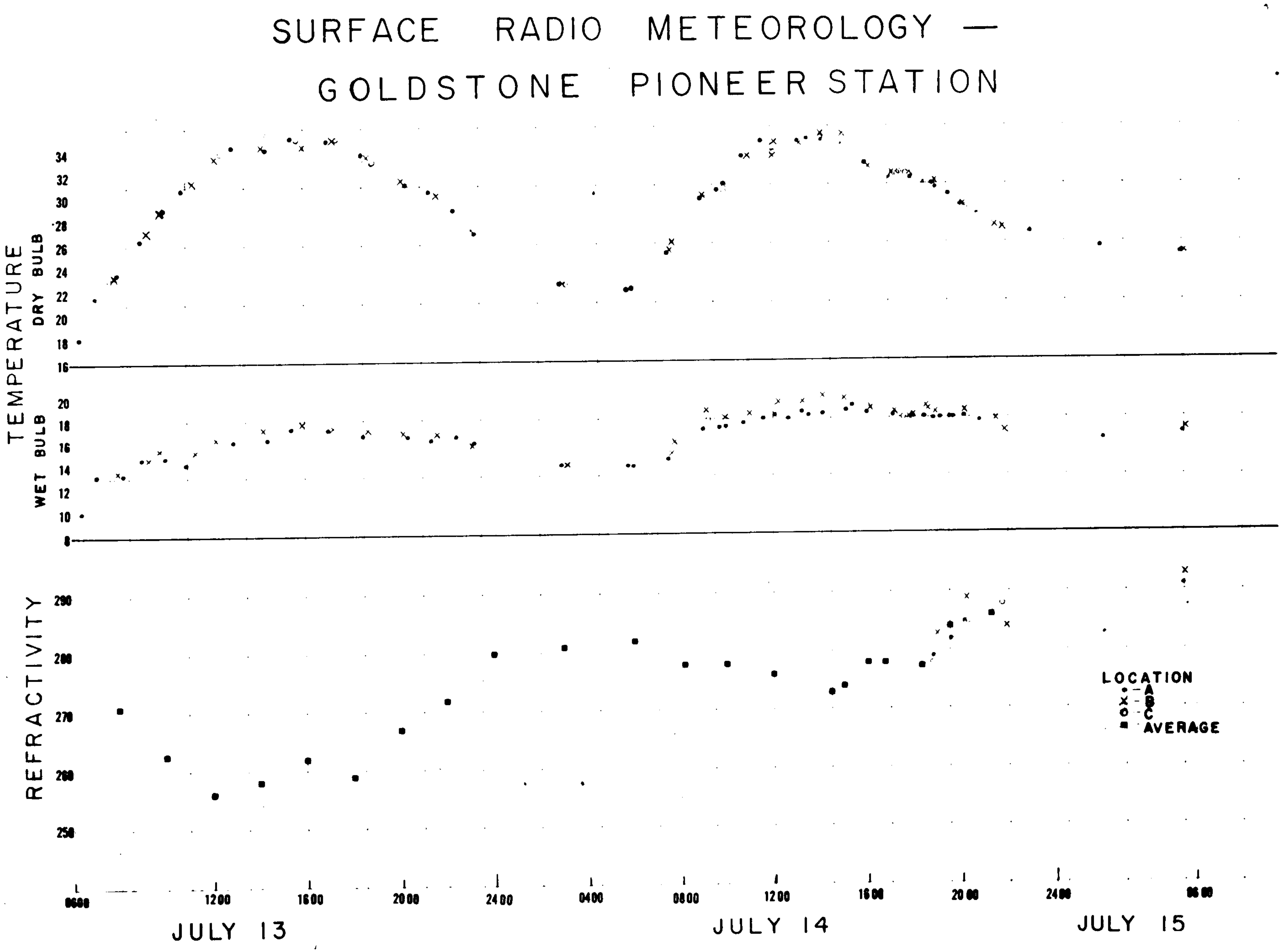

Figure 3 Surface radio meteorology Goldstone Pioneer Station

1,000 feet south of the Pioneer Antenna Site; Location C was located 3,000 feet south of the antenna site. Measurements made at these three stations were quite consistent and showed insignificant spatial variation between the locations.

Figure 3 is a plot of the dry bulb and wet bulb temperatures from July 13 to the morning of July 15. If the influx of moist, hot air had not taken place, the diurnal variation would have been very close to what is shown for the first half cycle of July 13. At the bottom of the figure 3 is shown the index of refraction variation during this period.

During the morning of July 14, 1965, there were considerable clouds over the Goldstone Pioneer location. By mid-afternoon cumulus clouds were in evidence over many mountains around the site; one example to the north of the location is shown in figure 4. Fortunately, by 1800 the clouds along the propagation direction had cleared away except for a few high level cirrus clouds shown in figure 5.

IV. METEOROLOGICAL MEASUREMENTS

A. RADIOSONDE

The radiosonde [3] is a balloon-born instrument package for measuring the pressure, temperature, and humidity of the air starting at the surface and going to approximately 100,000 feet. Resistance changes of the temperature and humidity elements control the audio modulation frequency of a blocking oscillator. The modified 1680 Mc/s carrier is transmitted to the ground where the temperature and humidity is recorded. The individual radiosonde package is calibrated on the ground before the flight and the pressure element adjusted to agree with the barometric pressure at the elevation for which the radiosonde is launched. The data are obtained by switching between the temperature and the humidity readings at specified changes in pressure.

Radiosondes are launched simultaneously twice each day at a number of stations throughout the northern hemisphere. Data are reported by all sondes at mandatory pressure levels of 1000, 850, 700, 500, 300, 250, 200, 150 and 100 millibars. Significant levels are recorded in between if significant changes in temperature or humidity are noted. The advertised accuracies for measuring the pressure, temperature, and humidity are included in the following table.

TABLE II

RADIOSONDE INSTRUMENT ACCURACIES

Pressure Level	Δ(P)	Δ(T)	Δ(R. H.)
1000 mb	± 1 mb		
500 mb	± 3 mb	± 0.5°C	± 2.5% *
100 mb	± 1.5 mb		
10 mb	± 1.5 mb		

* This value is for temperatures greater than -10°C. The temperature lag at a temperature inversion may produce large errors in humidity readings.

B. SURFACE TEMPERATURE MEASUREMENTS

Three houses for wet and dry bulb thermometers were constructed and a typical installation is shown in figure 6. The thermometers were all calibrated and their accuracies were known to be within ±0.1 of a degree centigrade. A small electrical fan was available for aerating the wet bulb. However, it was not used because the wind at Goldstone was always sufficient to keep the wet-bulb temperature depressed to the value given by a sling psychrometer.

C. MEASUREMENT OF AIR PRESSURE

Over a dozen readings of atmospheric pressure were taken at the Pioneer Tracking Station from July 12 to July 15. The changes seemed to follow a well-behaved trend. The minimum recorded was 901.9 mb at 0735 on July 12 and again at 0612 on July 15, with a slowly reached maximum of 904.0 mb around 1400 on July 13.

Because the pressure changes were small and gradual their effects on the refractivity of the atmosphere were no doubt unimportant, as compared with other weather variables, at the time of the occultation experiment on July 14.

V. RADIO PHASE VARIATION DUE TO TROPOSPHERE

At the frequencies considered, the index of refraction of the troposphere is not a function of frequency. The increase in travel time due to the troposphere can most conveniently be stated in terms of increased distance, which, when multiplied by $2\pi/\lambda$, gives the increase in phase of the field in radians. Table III compares the increase in distance at normal incidence for several tropospheric refractive index profiles. It was found that the radiosonde data for Yuma, San Diego and Las Vegas were best represented by the profile 349 exp [-0.1326 h] for elevations above 6 km. Between one and six kilometers the data were more scattered, but fairly well contained between the exponential profile 8 and the straight line profile of 9. These two extremes gave increased distance for the height interval between one and six kilometers of 1.06 and 1.12 meters, respectively. The mean of these values added to the 1.18 meters derived from the profile 3 gave a value of 2.27 meters for the total troposphere above the Goldstone Pioneer Station at 1800 on July 14, 1965. As a matter of fact, the profile given by 3 yields a value of 2.30 meters which is only 0.03 meters away from the above value. It is safe to conclude that the increased distance due to the troposphere over Goldstone at 7:00 p.m. on July 14, 1965, was quite accurately given by

$$\Delta h = 2.27 \pm 0.03 \text{ meters}$$

The total phase change for the path through the troposphere at the elevation angles θ under consideration is to a good approximation given by

$$\frac{2\pi}{\lambda} \cdot \frac{\Delta h}{\sin\theta}$$

The largest short period change in refractivity that could have taken place over the Goldstone Pioneer location at the time of interest would have been the drift of a fully developed cumulus cloud into the propagation path. If such a cloud extended from 2 kilometers to 5 kilometers and contained 100% humidity throughout, it could have increased the radio depth of the troposphere by no more than 0.14 meters beyond the above value. This, of course, did not happen, and it is quite unlikely that the changes which took place between 1900 and 2000 on July 14, 1965, were as great as

$\pm$ 0.02 meters. This would correspond to a change of 10 N units over a two kilometer distance. The observed changes in refractivity at the Pioneer Station were of this magnitude, but it is certain that these changes were due to cooling of the air at the surface; and consequently this modification did not extend above the antenna this early in the evening.

TABLE III

RADIO RANGE INCREASE DUE TO TROPOSPHERE

	Refractive Index Profile	ΔR (meters) Altitude Interval, h. Kilometers			
		$0 - \infty$	$1 - 6$	$6 - 13$	$13 - \infty$
1.	$465.0 \exp[-0.1568\, h]$	2.965	1.376	0.771	0.385
2.	$349.0 \exp[-0.1326\, h]$	2.631	1.118	0.718	0.468
3.	$340.0 \exp[-0.1326\, h]$	2.564	1.090	0.700	0.456
4.	$330.0 \exp[-0.125\, h]$	2.640	1.082	0.726	0.520
5.	$320.0 \exp[-0.1281\, h]$	2.498	1.037	0.684	0.472
6.	$316.0 \exp[-0.1176\, h]$	2.687	1.056	0.747	0.582
7.	$280.0 \exp[-0.1285\, h]$	2.179	.909	0.560	0.410
8.	$306.9 \exp[-0.112\, h]$	2.740	1.057	0.782	0.638
9.	$N = 310.5 - 25.5\, h$		1.123		

APPENDIX I

RADIOSONDE DATA

A. LAS VEGAS

1. Local time: 0500, 14 July 1965

   Station elevation: 679 meters

Pressure (mb)	Temperature °C	Dew point °C	Index of re-fraction N	Altitude (meters)	Wind direction	Wind speed (knots)
938	27.8	3.2	274.1			
928	30.8	10.8	290.2	756		
868	28.8	8.2	268.0	1,356		
850	27.2	7.5	263.2	1,536	180°	8
700	11.8	0.2	220.7	3,206	150°	14
684	10.0	-1.0	215			
524	-9.2	-13.8	165	5,577		
500	-10.5	-13.5	161	5,900	150°	16
485	-11.2	-13.8	155			
400	-21.0	-24.0	130	7,590	190°	18
300	-36.2	-43.5	100	9,650	210°	27
250	-45.2		85.1	10,890	210°	35
200	-55.8		71.5	12,340	190°	45
150	-64.0		55.7	14,130	220°	23
100	-64.8		35.6	16,600	150°	6

2. Local time: 1700. 14 July 1965

Station elevation: 679 meters

Pressure (mb)	Temperature °C	Dew point °C	Index of re- fraction N	Altitude (meters)	Wind direction	Wind speed (knots)
937	38.2	8.2	277.1	679		
927	35.5	13.2	294.0	778		
850	28.8	11.2	278.2	1,536	50°	4
700	13.2	3.8	226.8	3,217	220°	14
602	2.8	-2.2	195	4,550		
547	-2.5	-7.2	176	5,282		
500	-7.2	-14.2	158	5,940	160°	16
494	-7.8	-15.5	156	6,042		
467	-11.2	-17.5	149	6,501		
431	-14.5	-28.2	135	7,113		
400	-17.2	-25.2	128	7,640	170°	19
300	-33.8	-42.2	97	9,730	190°	33
250	-43.5		84.3	10,990	190°	43
200	-54.5		71.0	12,450	200°	31
150	-64.5		55.8	14,250	180°	27
100	-62.5		36.8	16,730	190°	12

3. Local time: 0500, 15 July 1965

Station elevation: 679 meters

Pressure (mb)	Temperature °C	Dew point °C	Index of refraction N	Altitude (meters)	Wind direction	Wind speed (knots)
937	29.5	12.2	298.9	682		
914	30.0	9.0	281.3	905		
850	25.8	6.5	262.0	1,526	350°	12
845	25.5	6.2	259.5	1,576		
700	10.8	0.5	211.5	3,190	90°	10
597	-0.2	-4.5	194	4,534		
500	-8.8	-11.8	162	5,890	190°	10
459	-12.8	-15.5	146	6,583		
451	-14.5	-17.8	142	6,735		
400	-21.2	-28.2	128	7,580	190°	12
350	-28.2	-40.8	111	8,440		
300	-36.2		98.2	9,640	200°	27
250	-46.0		85.5	10,880	210°	51
200	-57.5		72.0	12,330	210°	60
150	-65.0		55.9	14,110	250°	21
100	-65.8		37.4	16,560	340°	6

B. SAN DIEGO

1. Local time: 0500, 14 July 1965

Station elevation: 124 meters

Pressure (mb)	Temperature ^{o}C	Dew point ^{o}C	Index of re-fraction N	Altitude (meters)	Wind direction	Wind speed (knots)
1,000	16.2	14.2	341.0	124		
969	13.2	10.8	319.8			
947	14.2	12.2	319.8			
924	21.8	8.2	291.0	831		
892	23.5	-5.5	250.8			
850	22.5	5.5	261.8	1,522	150^{o}	8
700	10.2	0.8	222.5	3,177	130^{o}	12
593	0.8	-8.8	185			
500	-8.5	-16.5	156	5,880		
400	-20.5	-34.8	128	7,580	160^{o}	14
300	-35.5	-46.2	99	9,640	160^{o}	24
250	-44.5		84.8	10,890	160^{o}	33
200	-54.5		71.0	12,350	170^{o}	43
150	-63.8		55.6	14,150	210^{o}	16
100	-64.2		37.1	16,610	110^{o}	4

2. Local time: 1700, 14 July 1965

Station elevation: 124 meters

Pressure (mb)	Temperature ^{o}C	Dew point ^{o}C	Index of refraction N	Altitude (meters)	Wind direction	Wind speed (knots)
1,000	21.8	15.5	339.5	124		
990	17.8	11.2	324.5			
970	16.2	10.8	318.2			
946	23.5	15.5	323.1	632		
923	24.5	7.8	285.6	848		
850	21.5	2.2	255	1,534	200^{o}	13
814	19.2	7.5	261.5	1,930		
700	9.8	0.2	221.3	3,186	150^{o}	11
580	-1.2	-7.8	184	4,810		
500	-8.8	-16.5	154	5,890	30^{o}	5
400	-19.5	-28.5	127	7,580	150^{o}	13
300	-35.8		98.2	9,660	160^{o}	25
250	-43.8		84.6	10,900	160^{o}	23
150	-62.5		55.3	14,180	170^{o}	18
100	-65.8		37.5	16,640	160^{o}	8

3. Local time: 0500, 15 July 1965

Station elevation: 124 meters

Pressure (mb)	Temperature °C	Dew point °C	Index of refraction N	Altitude (meters)	Wind direction	Wind speed (knots)
1,000	16.5	15.2	346.5	124		
965	13.2	11.5	324.0	451		
895	24.5	6.8	275.4	1,106		
850	21.5	10.8	280.5	1,527	250°	3
782	17.2	5.8	250.1	2,279		
700	9.5	2.5	226.6	3,181	110°	3
615	1.2	-2.5	200	4,328		
500	-8.8	-15.2	157	5,880	150°	8
486	-10.2	-21.5	149			
417	-19.8	-24.8	133			
400	-21.8	-29.5	128	7,570	150°	27
300	-34.0		97.4	9,640	170°	31
250	-43.8		84.6	10,890	170°	51
200	-55.8		71.4	12,360	180°	59
150	-64.5		55.8	14,150	220°	18
100	-66.5		37.6	16,600	100°	6

C. YUMA

1. Local time: 0400, 14 July 1965

Station elevation: 124 meters

Pressure (mb)	Temperature °C	Dew point °C	Index of refraction N	Altitude (meters)	Wind direction	Wind speed (knots)
997	27.8	14.2	324.4	124		
941	29.5	13.5	305	666		
850	23.2	9.2	272.3	1,539	180°	14
700	10.2	6.2	236	3,197	140°	16
668	6.5	6.5	232			
559	-3.8	-3.8	186	5,104		
523	-8.8	-15.5	164			
500	-8.8	-16.8	157	5,900	140°	10
480	-10.8	-24.2	148			
436	-15.8	-21.8	139	6,978		
400	-20.5	-35.2	128	7,590	160°	14
300	-34.5	-40.2	100	9,660	160°	41
250	-44.8		85.0	10,900	160°	58
200	-56.8		71.7	12,350	170°	68
150	-64.2		55.7	14,130	220°	23

2. Local time: 0500, 15 July 1965

Station elevation: 124 meters

Pressure (mb)	Temperature °C	Dew point °C	Index of refraction N	Altitude (meters)	Wind direction	Wind speed (knots)
996	31.5	13.5	317.5	120		
981	31.8	14.8	318.5	303		
940	30.0	11.0	294.0	688		
850	23.8	7.8	267.4	1,534	160°	6
754	15.5	3.8	239.4	2,596		
700	9.0	0.5	222.5	3,190	140°	12
569	-3.2	-4.8	184	4,959		
500	-9.2	-10.2	162	5.890	340°	6
473	-12.2	-18.2	152			
457	-15.2	-26.5	144	6,560		
400	-19.8	-28.8	128	7,580	150°	18
300	-34.2	-42.8	100		140°	31
250	-44.8		85.0	10,900	140°	39
200	-57.0		71.8	12,350		29
150	-55.2		53.4	14.130	280°	18

REFERENCES

1. Crain, C. M., et al, "Measurement of Tropospheric Index of Refraction Fluctuations and Profiles," Proc. IRE, 41, pp 284-290, 1953.

2. Bussey, H. E. and Birnbaum, George, "Measurement of Variations in Atmospheric Refractive Index with an Airborne Microwave Refractometer." NBS Journal of Research 51, pp 171-178, 1953.

3. Ference, Michael, "Instruments and Techniques for Meteorological Measurements." Compendium of Meteorology, Am. Met. Soc., pp 1207-1222, 1951.